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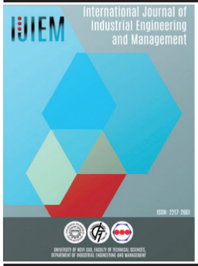

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Original research article

Supply chain risk prioritization using AHP and framework development: A perspective of the automotive industry

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ABSTRACT

Many studies have been done on supply chain risk management and identification, but there have been few works done on risk analysis, departmental integration, and mitigation framework design. The goal of this study is to help enhance risk management cooperation amongst supply chain departments. A questionnaire survey was conducted in a case automotive company and analyses were performed using Analytical Hierarchical Process (AHP) to find department-wise risk priorities so that integration between these departments can be improved. The findings demonstrated that some hazards were substantial for all departments and that problems related to their domain were frequently given top priority.

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1. Introduction

Modern supply chain design has become so unpredictable, that it's far more likely to pose a threat in disasters such as Hurricane Katrina in the United States, the tsunami in Thailand; earthquakes and tsunamis in Japan, and terrorist attacks such as the September 11 New York bombings, Somali pirate attacks; the Ericson fire accident, and the COVID-19 outbreak. These occurrences are a prime example of how unprepared and unskilled supply chains with no contingency plan may devastate the operations of enormous corporations. Hence, dealing with the threat of a supply chain system has become a significant challenge for many firms [1]. The high level of cooperation among supply chain members may assure the success of member bodies. Coordination among members may be done by an effective structure and an information exchange system [2]. Due to the supply chain's design fragility in recent times, the significance of losses has become a major research topic [3]. Controlling the supply chain is very critical

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to an organization's success and performance. In today's fast-moving economy, any unplanned risk could result in an extensive monetary loss if preventive measures are not taken in advance [4]. Problems in global supply networks are prevalent. Inconsistencies in processes and supply chain continuity are the primary source of concern. The supply chain must be adaptable and risk-aware in the case of an unanticipated interruption, without deviating from the intended strategic plan. The supply chain must be restructured in the case of a disruption [5]. A strong corporation can manage internal resources and set up a competent structure to deal with any unexpected problems that arise [6]. Efficient supply chain management is the process of synchronizing the flow of products, services, and data to improve customer satisfaction while lowering costs. Organizations these days cannot compete effectively without complete coordination between upstream and downstream partners within the web of supply chain networks [7]. The probability of such undesirable situations and their significant impact might jeopardize the supply chain's efficiency and effectiveness [8]. To avoid such failures, global supply chain partners must work together to build an active, proactive risk management strategy. Supply chain risk management evolved from the risk management field, which has been a hotbed of study for more than two decades [7]. In comparison to other industries, manufacturing produces and stores the most data. The effectiveness of business operations can be greatly increased by using data analysis and machine learning techniques [9]. Therefore, supply chains these days also require vast amounts of data analysis and information sharing.

Supply chain agility needs increasing collaboration and reliance on supply chain partners to satisfy customer demands while cutting processing costs and total response time [10]. The ability of a firm to engage with its partners to address and recover from any unanticipated interruptions while continuing to operate normally in its operational activities and structures is referred to as supply chain resilience [11]. The operational capability of a manufacturing organization in terms of resource planning, production capability in terms of making goods, marketing the products, and resource usage determines the manufacturing company's resilience [12]. There is significant work done on risk identification and prioritization, but very less attention is given to the inter-departmental coordination of the supply chain partners within an organization which is related to the fourth level of supply chain integration. The research question for this study is focused on how various supply chain elements in a company may coordinate and perceive risk on a departmental level, and what influence this will have on the supply chain structure to reduce the potential risks associated with this network. The research took into account the departmental managers' differing points of view and devised a strategy for developing a better framework once they can assess the risk from the other managers' perspectives as well. This research work includes a risk literature review to identify the most significant risks mentioned in the literature. This list of risks is then analyzed using AHP as the decision-making technique based on survey results. Based on this risk prioritization, a framework for improving inter-departmental coordination was developed, which will reduce risks within the supply chain.

2. Literature Review

A supply chain includes all the linkages within an organization that add value to the end product [13]. Over the previous two decades, supply chains have evolved from functional to technological to strategic. The supply chain is defined as a network or chain of business operations that manages supplies, finished goods, data, and cash flow [7].

2.1 Risk and Risk Management

Management of risk is a continuous process of controlling and eliminating risk in the early stage [14]. Risk assessment is described as analyzing and identifying possible risks that can occur within a project or a process. Such threats result in negative events that adversely affect the performance of a company or an entity. Literature suggests that risk assessment points out the key drivers and high-risk areas [14]. As a result, the hazard depends on the likely occurrence of an incident and its side effects on overall performance [15]. Jaffee et al. [16] defined risk as a potentially negative event that may cause damage to the total performance of a firm or organization and as a result have a highly negative impact on the performance of the supply chain. Risk can be defined as an occurrence or a set of circumstances that have an impact on the achievement of one or more goals [17].

2.2 Supply Chain Risk Management

Risk assessment of the supply chain plays a significant role in risk management and the approach used should be in line with the specific targets. Even though risks occur in both domestic and foreign supply chains, they have a significant impact on global enterprises specifically manufacturing enterprises. It's critical to compare and contrast the risks encountered by domestic and global supply chains in terms of the supply chain's goals [18]. Different economies, cultures, politics, infrastructure, and competitive environments must all be considered in global supply chains for risk identification and management [19].

2.3 Risk Identification in Supply Chain

Risk sources within the supply chain include variables specific to the organization, environment, or supply chain that influence the total supply chain objective [20]. Supply chain risks are classified according to the categories depending upon the extent to which they affect the performance of an organization [21] [22] [23] . Risks in the supply chain can be categorized into two types. Firstly, risks are caused by complications in the coordination of supply and demand, and secondly, risks are caused by disturbances in routine activities [24]. Christopher and Peck [25] in a study suggested that risks are classified as Internal to business (Control and Process), External to the organization but an integral part of the supply network (Demand and supply), and External Risks (Environmental). Tangen [26] classified threats into instability risks and operating risks. Ritchie and Brindley [27] categorized risks into seven different categories, including industrial characteristics, environmental characteristics, supply chain partners, organizational structure, supply chain growth, issue-specific variables, and decision-making units. Uncertainty-based classified risk: supplier quality, available capacity of an organization, production output, internal organization culture, delays in information flow, market action, policy setting, stock costs, customs regulations, and variation in the estimated cost. Gaonkar and Viswanadham [28] categorized uncertainty in the light of events leading to accidents, deviations, and disturbances. Operating risks are characterized as the built-in uncertainties that inevitably occur within supply chains, such as uncertain prices, volatile consumer demand, and unreliable supply. Wagner and Bode [29] classified supply chain risk factors into five categories: supply side, supply side, operational, government facilities, legal/bureaucratic, and calamitous.

There are three key sources of supply chain risks: the supplier side, the process side, and the demand side [30] . Natural catastrophes, political instability, and other environmental concerns must not be overlooked [31] . Furthermore, as a result of globalization, collaboration among partners is now regarded critical for any firm. Globalization carries with it not just opportunities but also risks such as partner insolvency, information leaking, and so on [32]. Furthermore, the financial components of any firm cannot be overlooked, such as cash flow issues, currency exchange risk, and pricing volatility [33]. Any financial disruption can have a significant negative influence on performance [34]. Finally, a supply chain is incomplete without flow, hence material movement is subject to risks such as accidents, delays, and other factors [35]. All of the risks stated above, including supplier-side risks, process-side risks, demand-side risks, environmental risks, logistic risks, collaborative risks, and financial risks, must be considered when assessing an overall supply chain risk [36].

Punniyamoorthy et al. [4] stated that supply-side risk, process-side risk, demand-side risk, logistic-side risk, information-side risk, and environmental risk are the six types of supply chain risk. However, this study did not examine financial risk on a case-by-case basis. Musa [37] on the other hand, divided the entire supply chain risk into six categories: source, make, deliver, finance, information flow, and environment. There is no single research that addresses all seven factors. Typically, the risk is divided into two categories: internal (direct) and external (indirect). However, supply chain research divides risk into three categories to cover all types of risks: internal to the organization, external to the organization but internal to the supply chain system, and external to the supply chain system [25] [29]. A detailed supply chain risk classification with major risk criteria and sub risk criteria based on the above-mentioned studies that would be used in this study is given in table No. 1 below:

Supply chain risk measurement is part of supply chain performance measurement. There are two key concepts for the assessment of the supply chain: The measurement system should be quantifiable so that it can be linked to objectives achieved through its adoption and all members of the supply chain agree on the goals of the same processes and the steps to be implemented [49].

2.4 Research Gap Analysis

Prioritization of objectives is a vital part of risk measurement within the supply chain. Risks amongst supply chains can be measured in both qualitative and quantitative manner [25]. Employee understanding of the proactive approach to risk manage-

Table 1. Supply Chain Risk Identification

Risk Areas	Sub Risk Areas	References
Government Risks	New Fiscal Policies, Government change, poor infrastructure, change in regulations, government restrictions	[29] [38] [39]
Delivery Risks	Delivery Failure (wrong location/ time/ quantity), damage in transit, delay in delivery lead time, disruption in transportation	[37] [4] [38] [36] [40] [41] [42]
Operational Risks	Production of damaged/ defective products, obsolete equipment, interruption in production, change in technology	[30] [37] [4] [38] [36] [29] [43] [44]
Market Risks	Level of competition within the market, market capacity, new entrants in the market, new market opportunity, unpredicted demand	[30] [4] [38] [36] [44]
Human Resource Risks	Resistance to change, labor strikes, employee availability	[40] [45] [21] [46] [47]
Product Risks	New product introduction, short product life cycle, process complexity	[48]
Supply Risks	Defected Raw Material Supply, delay in raw material supply, disruption in raw material supply	[1]

ment of the supply chain is indeed very significant. The threats to the stability of the supply chain and the prompt and effective response are important to employee training [44]. The qualitative evaluation is carried out by statistical analysis. However statistical tools only provide one-dimensional analysis with the usage of models which creates complexities for managers. Managers of the supply chain should be aware of the risk of evolving work practices within the supply chain. This in turn aids in mitigating these risks [7]. A well-designed supply chain cannot only bounce back from any unforeseen event but also can provide a proactive approach towards the risks associated. This is a preventive process where companies put in costs to avoid any unforeseen calamity [7].

For a reliable supply chain, high mobility, speed, and large rates the alliance of all supply chain partners is extremely important [11]. According to the collaboration principle, without cooperation from global supply chain companies, risk management in highly interconnected global supply chains cannot possibly be appropriately assessed. There are many different aspects to collaboration, but trust and knowledge exchange are frequently stressed [50]. As a result, proactive methods to supply chain management are built on constant analysis, review, and risk allocation across all links. It employs a risk assessment method while also keeping a close eye on impending occurrences. The coordination of the supply chain in relation to network risks is still a topic with many unexplored aspects, according to a thorough literature analysis of the linked subject. This research is based on a proactive strategy to deal with supply chain risks within a company. This study aims to determine whether practitioners in an organization's supply chain, such as marketing, logistics, and material management, perceive risk in the same way, as well as the system design and techniques for strengthening dyadic relationships between supply chains and reducing supply chain risk. The vulnerabilities inside an organization will be examined based on the responses of an automobile organization's employees. The disparities in opinion among supply chain departments will be emphasized, and a structure based on information exchange will be established. To examine risk prioritization, the research will employ the multi-criteria decision-making technique of AHP (Analytical Hierarchical Process).

3. Methodology

Quantitative risk analysis was carried out in this research. This research was divided into phases for a better review of the literature and methods implied by various researchers. Phase I comprised of extensive literature review of the research papers written on the topic of supply chain risk management. Phase II of the research included the compilation of a listing of supply chain risks from the literature that could be sorted in order of preference. Phase III of the research was the questionnaire design. The questionnaire was designed according to the risk areas highlighted in Figure 2. It was designed to the comparison between two scenarios and choose the most preferred scenario among the managers. The scale between the scenarios was marked between 9-1 and 1-9 between scenarios. Phase IV of the research was data collection. Data was collected from an emerging automotive company in a developing country with employees and a wide range of product variety. Senior management, middle management, and junior management staff from supply chain linkages of the said organization were asked to complete a questionnaire based on the AHP in order to provide their responses. Notably, each decision maker entered the desired amount for each participant, and the individual judgments (of each respondent) were then converted into group judgments (for each of the pair comparisons) using their geometric mean. For our reference the supply chain was distributed in four stages:

Phase V consisted of questionnaire analyses using multi-criteria decision-making techniques to transform qualitative data for risk preference into quantitative data so that risks might be prioritized accordingly. The Analytical Hierarchical Process is used to calculate the preferred risks from the provided risk lists. AHP was used in calculations because it solves complex problems with many criteria with accuracy. The intended AHP hierarchy is depicted in figure 2; the number of sub-criteria is not fixed to be equal.

AHP breaks up and divides the complex problem in terms of priorities, features, and alternatives into hierarchical structures. The decision-maker then decides their priorities in the pairwise correlational matrix using an integer ranging from 1-9 or their reciprocals respectively. If a selected priority is compared with itself, it is marked as '1' the numbers 3, 5, 7, and 9 denote moderate, strong, very strong, and extreme judgments respectively, and numbers 2, 4, 6, and 8 show an intermediate selection between two odd values of moderate, strong, very strong and

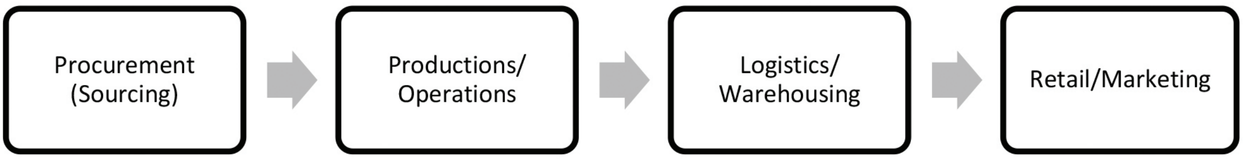

Figure 1. Supply Chain Linkages for the Research

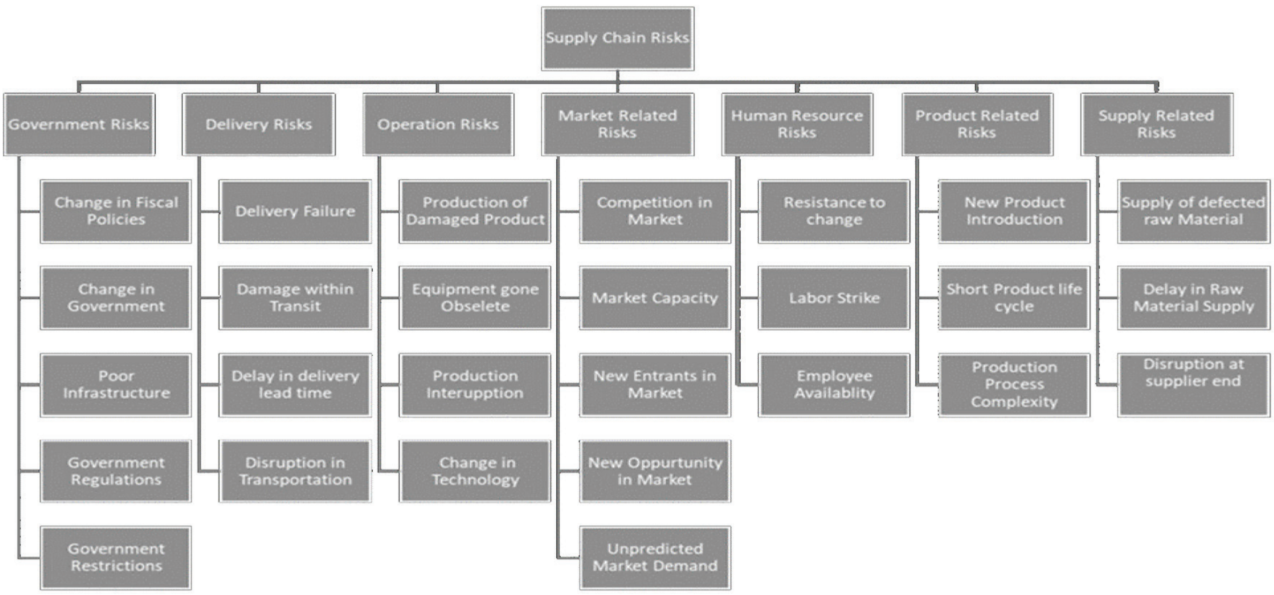

Figure 2. AHP Hierarchical Distribution

extreme [51]. The marking or selection scheme is briefly explained in the table below:

Table 2. Relative Scale of Preference in pairwise comparisons [52]

Judgment or Preference	Numerical Rating
Extremely Preferred	9 8
Very Strongly Preferred	7 6
Strongly Preferred	5 4
Moderately Preferred	3 2
Equally Preferred	1

The steps involved in AHP are defined below [51]:

(1) The hierarchical structure should be properly stated and developed, with the topmost level being the objective or main objective, the second level being the desired criterion, and the third or final level being the alternatives to be picked.

(2) Pairwise matrix comparison is then created from the choices between criteria in the hierarchy's second level. The characteristics at the higher level are measured in pairs according to the defined criteria.

(3) The priority vectors for each matrix in the hierarchy would then be created using a prioritization technique. The Eigenvector equal to the Largest Eigenvalue of the considered matrix is then used to determine the weights of each comparison matrix. i.e.,

$$Aw = \lambda \max w$$

(4) Where 'w' is the priority vector and 'A' is a consistent pairwise comparison matrix. The separate weights are added to determine the weight of each option at the bottom of the hierarchy.

(5) After of the calculation, a consistency check is run to ensure that the pairwise comparison matrix judgments are made properly and thoroughly. The consistency ratio (CR) of a pairwise comparison matrix is calculated by using equation (1):

$$CR = \frac{\lambda\, max - n}{n-1} / RI \qquad (1)$$

Where RI corresponds to the random inconsistency index and is extracted from table 3. Here 'n' refers to the order of the pairwise comparison matrix.

If CR comes out to be less than 0.1, the pairwise comparison matrix is under an acceptable range of consistency; otherwise, the judgments are to be revised [14]. AHP is used to define and analyze the risk factors within the supply chain to achieve the goal of a perfect order index. Calculations were done based on the answers obtained via the designed questionnaire. The risk priorities were marked by focused group discussion at the three (senior, junior, and middle) managerial levels. An AHP calculator was designed using Microsoft Excel and then values were inserted to extract the answers. This research was fragmented into seven risk criteria and calculations were conducted to compare the risk sub-criteria amongst the four supply chain departments.

Phase VI consisted of desired framework design based on the analyses. A theoretical framework is proposed for an effective and resilient supply chain where the focus is on the coordination between supply chain linkages so that any risks within the supply chain can be avoided with an integrated approach.

4. Results

An analytical hierarchical process was utilized to calculate the risk preferences of each department. The results were analyzed to select the top five risk preferences in each department. Figure 3 shows the top priorities for the procurement department. The procurement department gave the highest priority i.e., 71.3 % to disruption at the supplier end which is a sub-criteria of supply risks. This could seriously affect the production timeline and procurement reputation. Other top risks included delay in delivery lead time (delivery risks) which comes out to 64.43 %, interruption within production (operation risks) which comes out to be 53.53%, change in fiscal policies

Table 3. Relative RI for Matrix order [52]

Order of the matrix (n)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(government-related risks) which comes out to be 46.38%, and unpredicted market demand (market-related risks) which come out to be 44.75%. Hence it can be noted that supply risks are of high importance for the procurement department as these are the risks related to procurement operations. However, the procurement department also values delivery, production, government, and market-related but with a lesser percentage.

Figure 4 presents the prioritization results for the production department. The production department gave the highest priority to Obsolesce of equipment which comes out to be 61.02%, this is the sub-criteria of operations risk and could pose a high threat in today's ever-changing and competing market. The other risks that were given high weights in decision making were disruption at the supplier end (supply risks) - 60%, damage of product in transportation (delivery risks) – 48.26%, and the complexity of the production process (Operation risks) – 45.77%. The results indicate that operational risk criteria are most important for the production department. Supply risks and delivery risks also carry a considerable weightage. However, the production department gives very little weightage to human resource risks, government risks, product risks, and market risks.

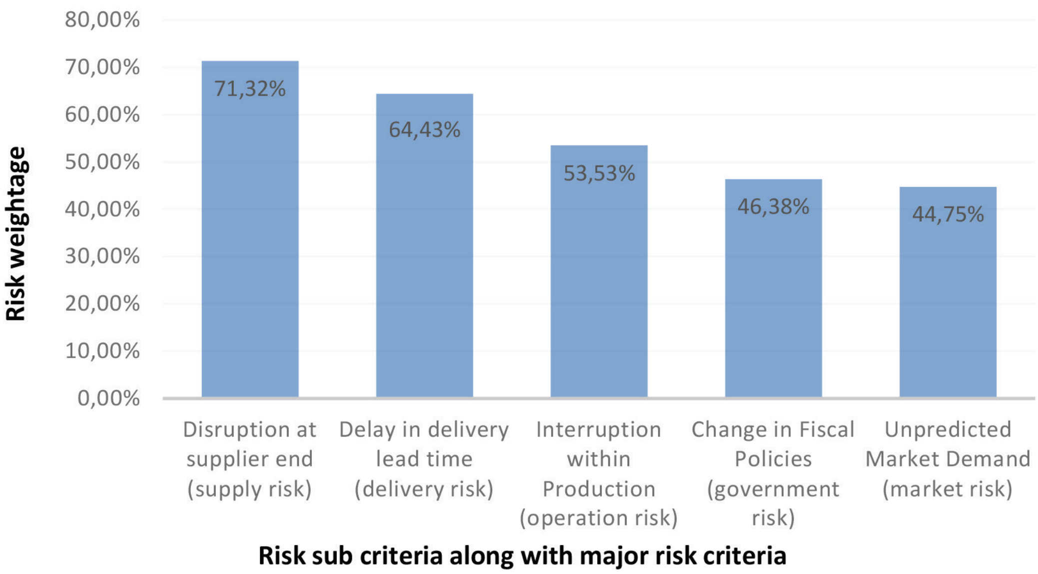

Figure 3. Top Priorities of the Procurement Department

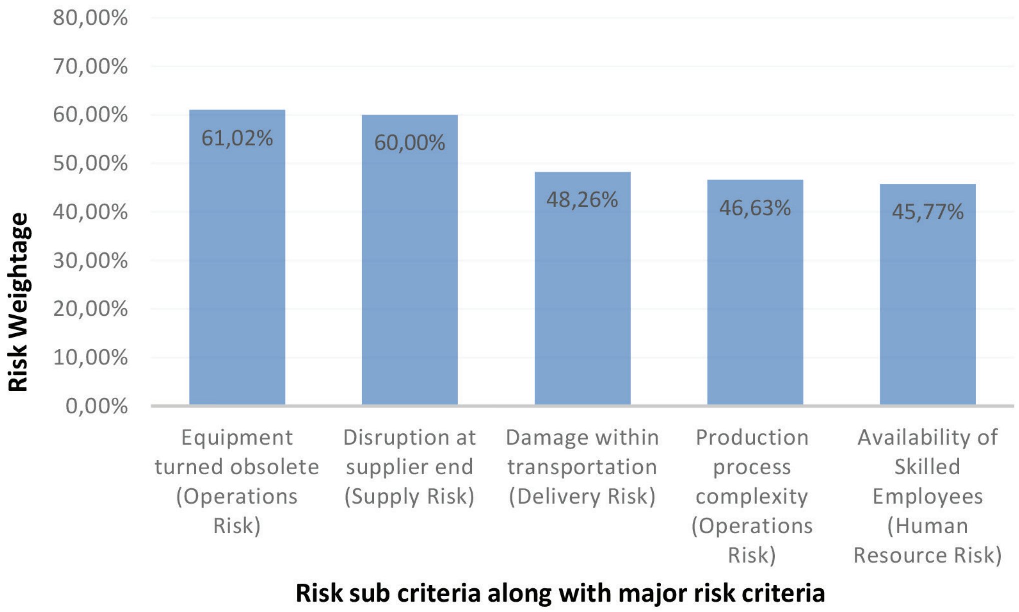

Figure 4. Top five risk priorities in Production Department

Figure 5 shows the top priorities of logistics department in an organization. The logistics department considered the availability of skilled employees which is the sub-criteria of human resource risks as the highest risk in their point of view since unskilled or untrained staff can cause damage in transit and storage. This comes out to be 71.32%. This could cause financial loss to the organization. Other top-priority risks included new product introduction risks (product-related risks) which comes to be 71.32%, disruption at the supplier end (supplier-related risks) which comes to be 71.32% again, disruption in transportation (delivery-related risk) comes fourth with 62.64%, and government restrictions (government-related risks) comes fifth with 56.30%. The results show that for transportation and logistics workforce training is very important.

Figure 6 shows the top priority risks for the marketing department. Marketing gave the highest priority to Labor Strike which is a human resource category risk this comes out to be 74.82%, the other top priorities included change in government regulations (government risks) which comes out to be 49.40%, new product introduction risks (product risk) which is 46.67%, production process complexity (operations risk) which is 46.67%, and failure in delivery (delivery risk) which was ignored or given very less priority by other departments this comes out to be 39.67%. The marketing department hence primarily focuses on the risks that can alter the image of the company.

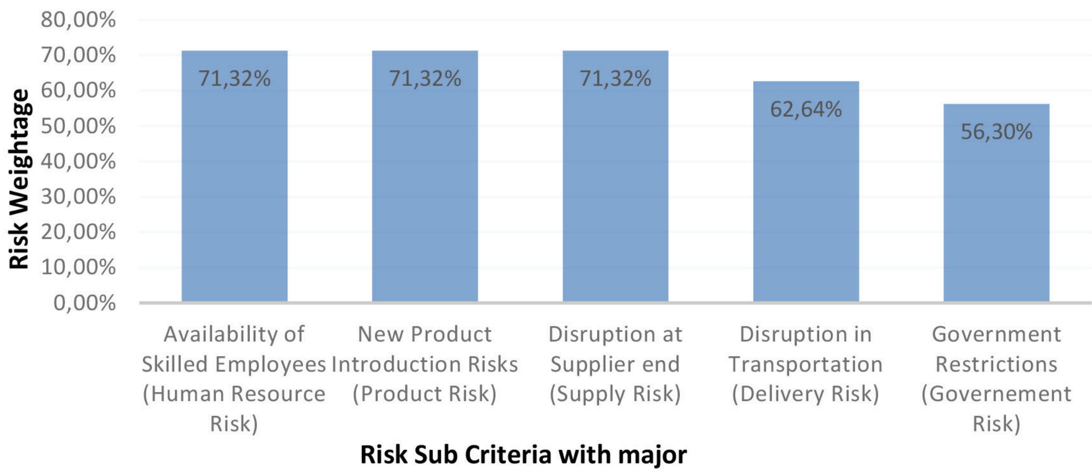

Figure 5. Top five risk priorities for Logistics Department

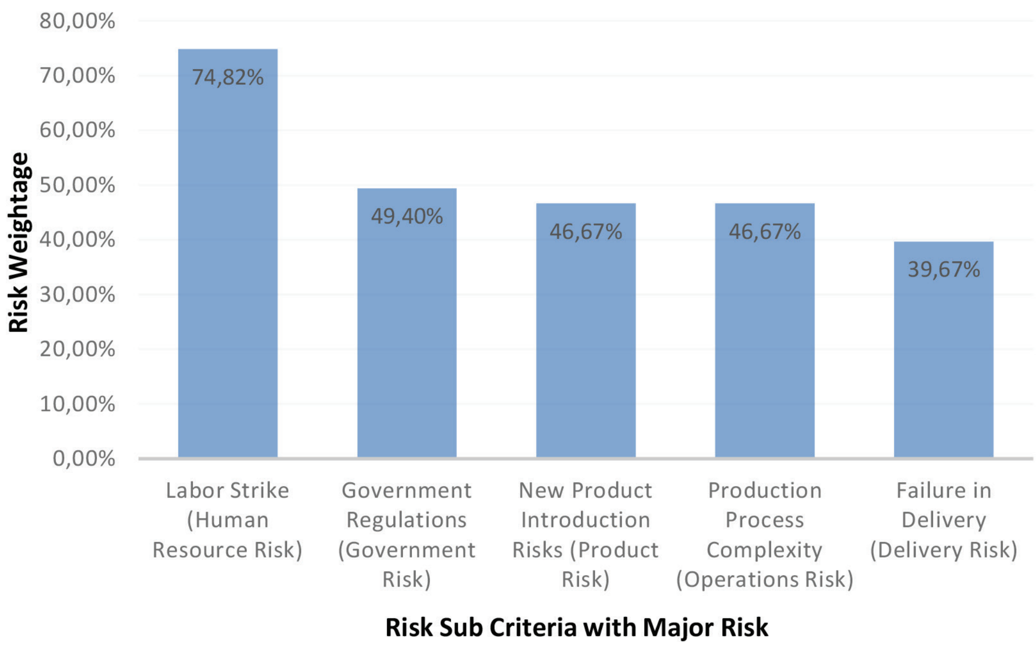

Figure 6. Top five risk priorities for Marketing Department

A theoretical framework was suggested to mitigate the risks within supply chains based on these results was proposed as presented in figure 7. The basis of the framework was the information sharing amongst the links of the supply chain to mitigate the risks, which as discussed earlier is the fourth stage of supply chain integration. The first step of this theoretical framework would be an annual questionnaire-based survey as carried out in this research. The risk priorities of every department will then be shared amongst the major stakeholders i.e., all the departments that constitute the supply chain of the organization so that the risk priorities of each department are known to all the relevant linkages. The common risks of all the departments will be highlighted and will be given special attention for designing mitigation strategies. Employee output regarding the policy designing for mitigation strategies will be given high weightage.

The managers of different departments within the supply chain can use the suggested framework to mitigate the risks in the initial stage of planning and can devise a better strategy to make the supply chain more resilient and robust.

5. Discussion

The different points of view or perspectives of each supply chain link within are visible in the above-mentioned results, which was the major research question in this study i.e., to study the difference of perspective. All five supply chain departments selected different risk criteria clearly showing that high level integration is needed for an organization to plan a mitigation strategy. The resultant risk priority selection by each department clearly shows that departments require alignment and result sharing to mitigate the pinpointed risks within the supply chain to avoid any future risk situation. One common risk factor amongst the first three links of the supply chain was disruption at the supplier end which is the sub-criteria of supply risk, but Marketing did not give very high priority to this, hence showing the stark difference in the thought process of technical vs non-technical departments. These results were all under a specified consistency ratio of 10% which means the decision-making was a result of a logical thought process. The resultant theoretical framework can be of greater use in industry. This framework will aid managers across the supply chain departments to proactively strategize the risks that are present in the process. These are helpful in supply chain alignment with a factor or risk induced in between so that departments can investigate other departments' points of view for better coordination and integration with terms of risk mitigation.

6. Conclusion

To demonstrate how the suggested approach and framework for risk prioritization and mitigation are applied, a real case study involving an automotive manufacturing facility is provided. To analyze the department-wise priorities, an analytical hierarchical process is applied to the identified risk sources. The suggested method is used to identify the most important sources of risk and to comprehend the value of information sharing. Since the method used here can be applied to other industrial and SCM areas as well, the proposed approach may be interesting to academics as well as risk management practitioners. However, the chosen strategy may be constrained by how it views respondents' hazy decision-making processes and the dynamic, constantly evolving nature of modern society. Supply chain risk management is a very open field for research, and it has many gaps that need to be addressed to make modern supply chains resilient and more prone to dangers. The areas of the gap in this particular research can be adding more risk areas in our analyses such as information technology risks, financial risks, etc. The domain of analyses can be increased to more than one type of industry and a supply chain structure should be framed for implementation to see the practical results of research or a hybrid model of two or more multiple criteria methods to be designed for a more precise approach towards risk mitigation.

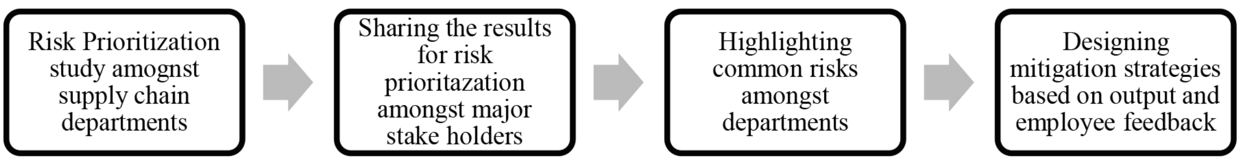

Figure 7. Framework for information sharing and risk mitigation

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